MEMOIRS OF THE ARCHÆOLOGICAL SURVEY OF INDIA

No. 15

The Drawing of Geometric Patterns in Saracenic Art

BY

E. H. HANKIN, M.A., D.Sc.

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E. H. HANKIN, M.A., D.Sc.

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PREFACE.

Dr. Hankin having retired from service in India the work of editing this memoir has principally devolved upon me. In going through the manuscript and plates it occurred to me that it might be of interest to the reader to see how these Saracenic patterns, the construction of which has been so ably described by Dr. Hankin in the following pages, can be adapted to modern wall or ceiling decoration. I have, therefore, introduced a plate (Plate XIV) showing two photographs of the Club at Agra, of which Dr. Hankin was a member for over twenty years and in which he supplied designs of his own conception or copies of ancient patterns from Fathpur-Sikri, Sikandra and elsewhere for the decoration of various rooms.

J. F. BLAKISTON,
Offg. *Deputy Director General,*
Archæological Survey of India.

Sept, 22, 1923.

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THE DRAWING OF GEOMETRIC PATTERNS IN SARACENIC ART.

INTRODUCTION.

ONE of the main characteristics of Saracenic art is its universal employment of geometric patterns often of amazing complexity. A reason for the employment of such patterns is that the portrayal of living things was forbidden by the Muhammadan religion. That a geometric pattern readily becomes monotonous by repetition goes without saying. Variety, therefore, was indispensable, and this desire for variety inevitably led to the discovery of new and complicated designs, so subtly complicated that it is hardly credible in some cases that the ordinary person could appreciate their nicety or distinguish, for example, between a pattern that contained 15-pointed and one that contained 18-pointed stars, or understand the purpose of changing a scheme of 10-pointed stars to one of eleven.

As to the origin of Saracenic patterns, Captain Creswell of the Egyptian Archæological Department kindly permits me to take the following quotation from a very interesting letter he has sent me on the subject :—

"The researches of the last twenty years have made it abundantly clear that the Arabs brought nothing architectural with them from Arabia but their very simple ritual requirements. Moreover, the armies of primitive Islam were composed of Bedwin, chiefly from the heart of eastern Arabia, knowing Muhammad and the Qurān merely by name, who had gathered together, not to take part in a religious war for the propagation of the faith, but in the hope of gratifying their lust for loot.......Of buildings of a permanent nature dating from the earliest period we have Quṣair 'Amra found by Musil. This building, a royal bath and resting house, is of simple plan ; it is roofed with tunnel vaults and a small dome, and, most remarkable of all, is decorated with figures, painted by Byzantine artists, including one of the Khalif enthroned ; there are inscriptions in Greek and Arabic (date 712-715 A.D.) but everything is quite Byzantine. Slightly earlier is the Dome of the Rock at Jerusalem, which was once decorated without as well as within with Byzantine gold mosaics, and the great mosque at Damascus was decorated in the same way.

"On the Persian front it was to the Persians that the Arabs turned for help. The first man with ambitions in the architectural line on this front was Ziād ibn Abīhi, Governor of Basra, who about 60 A.D. employed Persian workmen, and among them a man who had been a builder to Chosroes, who recommended the cutting of columns from Ahwaz marble, etc., etc.

"The only truly Arab period was the Umayyad, and this dynasty came to an end in 750 A.D. After this the Abbasids came and founded Baghdād, the whole centre of gravity was displaced and at the present day we cannot point to a single Muhammadan monument in Syria between the eighth and the end of the eleventh century.

"After the fall of the Umayyad dynasty Persian influence dominated, the superior brain power of the Persians displacing the proud but useless Arab grandees, and everything took a Persian tinge.

"Gradually, very gradually only, Muhammadan architecture was born, but it took two centuries to acquire a distinctive character. Sāmarrā succeeded to Baghdād about 836 A.D. Sarre and Herzfeld have excavated Sāmarrā and their publications and those of Viollet show that the geometrical interlaced straightline ornament had not yet been born there.

"The first building in Egypt to deserve the name of architecture was the mosque of Ibn Tūlūn, which exhibits the dominating influence of Sāmarrā, Ibn Tūlūn's former home. Tūlūnide ornament is illustrated in my article in the Indian Antiquary wherein I published a short note with three plates. The lattice windows of Ibn Tūlūn belong to two periods: 876-9 and the restoration of Lagīn in 1296. The earliest ones are based chiefly on compass work; at Al Azhar the oldest work is not geometrical. In Al-Ḥākim's mosque (980-1012) we get the first truly geometric ornament. It occurs in stone, one or two grilles in the north minaret being pierced with a simple six pointed star which may possibly be derived from prolonging the lines of the "Shield of David," until they strike a circumscribed circle.* The basis here suggested actually forms the chief decorative motive of the so-called "Gates of Somnath" brought to India from Mahmūd's mausoleum at Ghazni (997-1027).

"This simple grille is the only thing of its kind which certainly dated from Al-Hākim except some simple windows. The first dated example in wood is the *mimbar* at Hebron dated 484 (=1091 A.D.)........When we come to the middle of the 12th century we get eight and ten pointed stars, *e.g.*, on the pulpit in the Aqsa mosque at Jerusalem made at Aleppo in 1168 A.D.

"But during the Fatimide period in Egypt (969-1172) patterns such as this are rare in woodwork, quite different decoration being employed. Rich examples of this sort of thing, executed in stucco, are found in Persia at this date. Interesting, also, is the *mimbar* of the mosque of Sidi Okba at Kairawan. (See Flury "*Die Ornamente der Hakim und Azhar Moschee*" and Saladin's monograph).

---

* This pattern is shown in Plate I, Fig. 4.

"One last and very significant point, nearly all the technical words in Arabic used as architectural terms are of *Persian origin*."

It is surprising that, despite the complexity of Saracenic patterns, the geometrical knowledge required either for drawing or for designing them is small. Any one who can draw one line perpendicular to another, who can describe an equilateral triangle, and who can bisect an angle, is capable of copying these patterns and, with the methods about to be described, of designing new ones. Formal methods of making pentagons or heptagons, such as may be found in works on geometrical drawing, probably were not employed. If it is required to draw such figures, or any other polygons, all that is necessary is to describe a circle and to divide its circumference into the requisite number of equal parts, by trial and error, with the help of ordinary dividers.

That the builders of the Taj at Agra were incapable of drawing the particular class of pattern about to be described as "geometrical arabesque" seems probable. The method of drawing such patterns is quite unknown at the present day in India and during a visit to Cairo, some years ago, I found no evidence that it was known to the Egyptian workmen. They were making beautiful products of Saracenic art, but appeared never to attempt to reproduce the more complicated patterns that had been used by their predecessors. Lack of knowledge of the methods appears also to handicap European artists when copying the more elaborate achievements of Saracenic art. For instance, Prisse d'Avesnes, in his magnificent work *La décoration Arabe*, gives a series of coloured plates. Of these, 64 contain geometric patterns of which no less than 60 belong to the classes of patterns that are easy to draw, namely the hexagonal, the octagonal and the decagonal. The only book known to me containing a large collection of the more complicated designs is *Le trait des entrelacs* by J. Bourgoin. This book contains 190 plates of geometric patterns shown as plain line engravings without colour. But elsewhere one looks in vain for illustrations of the more complicated of these patterns in decorative work, the fact being that in selecting these designs for illustration, the European authors have almost invariably chosen those patterns which are relatively easy to draw. Bourgoin's drawings are made with wonderful skill and industry, but the description he gives of the geometrical construction of the patterns is of little practical use and serves merely to show how his remarkable skill as a draftsman has enabled him to surmount the difficulties of his task.

Of Saracenic patterns those made on hexagonal and on octagonal bases are drawn with ease. Any one who will devote a little trouble to the subject can without difficulty find methods as good as or better than those described below. But there is another class of patterns of the first importance in Saracenic art that is peculiar to this school, and which I propose to designate by the name "geometrical arabesque". The original method of constructing these patterns has long been forgotten and in its absence the work of reproducing them is most laborious and difficult. During visits to Fathpur-

Sikri many years ago, I spent much time in measuring the angles and making tracings of these designs but always failed to find any rational scheme by which they could be constructed. At last, by good fortune, I happened to enter a small Turkish bath attached to Jodh Bai's Palace. It had previously been inhabited by Indians, who had only just been evicted, and I was probably the first Englishman to visit the place. In one of the rooms of this bath was a half-dome decorated by a straight line pattern. In addition to the pattern, some faint scratches were discovered on the plaster. Obtaining a table and chair and a piece of tracing paper I succeeded in making a copy. On closer examination these scratches were found to be parts of polygons, which, when completed, surrounded the star-shaped spaces of which the pattern was composed, and it turned out that these polygons were the actual construction lines on which the pattern was formed. As will be explained in detail below, in making such patterns, it is first necessary to cover the surface to be decorated with a network consisting of polygons in contact. Then through the centre of each side of each polygon two lines are drawn. These lines cross each other like a letter X and are continued till they meet other lines of similar origin. This completes the pattern. The original construction lines are then deleted and the pattern remains without any visible clue to the method by which it was drawn.

After considerable labour in working out details I have at length elaborated the method by which one can draw complicated arabesque patterns and even design new ones. The room in which this clue was found is very dark, so perhaps this is a reason why the artist carelessly forgot to obliterate his construction lines, which have lasted for three and a half centuries and now give us an insight into a forgotten art.

I. HEXAGONAL PATTERNS.

We will commence with hexagonal patterns, which are perhaps the easiest of any to draw. To make such a pattern, begin by covering the space to be decorated by a number of oblongs of the shape shown in Plate I, Fig. 1. This is done by drawing two circles of the same radius and overlapping each other, so that the centre of one lies on the circumference of the other. The two circles intersect at C and the line joining C with the centre A makes an angle of 60 degrees with the line AB. The oblong is drawn in, as shown by the dotted lines and its diagonal makes an angle of sixty degrees with the base. It may, therefore, be referred to as the "60-degree oblong."

The space to be decorated must be so proportioned that it will contain a whole number of such oblongs. For instance, the panel shown in Fig. 2 contains three of them. If the space should be a little wider or a little higher, so that the three oblongs do not exactly fill it, it will be unsuitable for a hexagonal pattern, unless a large number of sixty-degree oblongs drawn to a smaller scale can be made to produce an exact fit.

Fig. 3 shows the method of constructing the simplest hexagonal pattern. The original oblong is ABCD and each side of it is divided into three parts. Cross lines are drawn from these divisions both horizontally and vertically and thus the space is divided into nine smaller oblongs. The diagonals of the oblongs are now drawn. By this means we cover the space to be decorated with equilateral triangles, some of the sides of which are used to form the pattern as shown at E and F.

The pattern consists of hexagons in contact, and each of the four corners of the panel corresponds to the centre of a hexagon. If two, three or more repeats are used to fill the panel, in each case the corners of the panel invariably coincide with the centres of hexagons of the pattern, and a fundamental rule in the use of these patterns has been observed.

The modern craftsmen of Agra usually employ hexagonal patterns, but they are ignorant of the correct method of drawing the sixty-degree oblongs. They begin by covering the space to be decorated by oblongs the sides of which are in the ratio of two to three. Hence the diagonals form an angle with the base of a little less than sixty degrees. The resulting patterns appear to be correctly drawn on a cursory inspection, but, if the hexagons are measured, it will be found that two diagonals out of the three are of the same length but that they differ slightly in length from the third. By measuring in this manner modern work can generally be distinguished from old.

A commonly used hexagonal pattern is shown in Fig. 4. It consists of six-pointed stars and hexagons with each corner of the repeat corresponding to the centre of a star. The repeat ABCD comprises four horizontal rows of six 60° oblongs. The area of the repeat of this pattern, namely EFGH, has a diagonal FG which makes an angle of about 50 degrees with the base. (An angle of 60° is indicated by the line FK from which it may be readily seen that this pattern of the star and hexagon is suited to panels differently proportioned from those required for the simple hexagonal pattern of Fig. 3.)

The utility of this method of construction is exemplified in Fig. 5 where the same pattern is drawn in perspective. The panel is made up of three repeats of the pattern. Each end of the panel is divided into four parts and horizontal lines are drawn to join the points of division. These are not parallel to each other but would meet, if prolonged, at a point outside the figure. Vertical and diagonal lines are drawn in as before and from this ground-work the pattern is easily completed.

An hexagonal pattern often used at Agra is shown in Fig. 6. In this case the repeat includes six rows of six sixty-degree hexagons and the diagonal of the repeat makes an angle of sixty degrees with the base.

In Fig. 7, the pattern has a repeat consisting of seven horizontal rows of seven sixty-degree oblongs The pattern includes hexagons, large hexagonal stars and diamonds which correspond to the construction lines. It has in addition smaller hexagonal stars which are drawn independently of the original construction lines. This pattern is taken from "*Le trait des entrelacs*"

by Bourgoin, Plate 20. Another hexagonal pattern, in which some of the lines do not correspond with the original construction, is shown in Fig. 1 of my paper "*On some discoveries of methods of design in Mahommedan Art*" (Journal of the Royal Society of Arts, 1905, Vol. 53, p. 461). This pattern is to be seen in the so called "blindman's-buff house" at Fathpur-Sikri where it is used in a lattice-work window opening of red stone.

Sometimes, instead of being arranged with their longer sides in a vertical position, the sixty-degree oblongs may be laid horizontally, as shown in Fig. 8 where it will be noted that the diagonal of the repeat forms an angle of 50 degrees with the base. This pattern was found in a tomb near Delhi. In Fig. 9, is shown a pattern that occurs frequently at Agra in stone trellis balustrades. Here the area ABCD consists of two repeats divided by the line EF.

2. OCTAGONAL PATTERNS.

The repeat of octagonal patterns is invariably a square and, therefore, their use is restricted to spaces which are either square in shape or are made up of any whole number of squares. The simplest octagonal pattern consists of octagons in contact leaving squares between them as "residual spaces" as shown in Plate II, Fig. 11. A method of drawing this pattern is illustrated in Fig. 10. Here the surface is divided into squares and the diagonal of a square is drawn and then prolonged as at CD. The diameter of the same square is likewise prolonged as at AB, and O is the centre of the square. From the centre O draw an arc of any convenient size (EF). With E and F as centres mark off two arcs, which will intersect at G, and then join OG. This line GO cuts one side of the square at L. From the adjacent corner H draw a circle with a radius LH and repeat these circles at the corners of the other squares. In each circle inscribe a square as shown at K by dotted lines. These squares and the lines joining them together form the octagons which are shown in Fig. 11.

In Fig. 12 is illustrated a pattern formed by octagons superposed. This pattern is found in the pavements of the pathways in the Taj Mahal garden at Agra. The design is made by repeating the previous construction in such a position that the centres of the second set of octagons coincide with the centres of the original squares.

Another pattern can also be made by octagons in contact, in this case by their angles as shown in Fig. 14, and not by their sides as in Fig. 11. To draw this pattern, the area to be decorated should be covered with squares and in one of the squares a circle, as shown in Fig. 13, inscribed. With its centre at the corner of the square then describe the small circle ABCD with such radius that it touches the larger circle, and repeat these circles at the other corners of the squares. The circumferences of the small circles, it will be seen, are cut by the diagonals of the squares, as at the points A, B,

C and D. If these points are joined to similar points on neighbouring circles by lines such as AE, BG and BK and all the circles are treated in this way, the pattern (Fig. 14) will thereby be completed.

A pattern may be formed by octagons overlapping by two sides as depicted in Fig. 16. To draw it cover the surface with squares as indicated by dotted lines in Fig. 15 and surround each group of four squares by a circle. In each circle describe an octagon as shown in the figure. It may be noticed that the circumference of each circle is divided into eight equal parts by the dotted lines forming the ground-work of squares, so with this foundation the drawing out of the octagons presents no difficulty.

The design shown in Fig. 18, occurs frequently in perforated stone screens or balustrades in Agra, and the method of drawing it is illustrated in Fig. 17. Commence by covering the surface with octagons with their sides in contact and at intervals superpose on these octagons other octagons as A, B, C and D. The centres of the original octagons are then joined in such a way as to form the squares E, F and G. The remaining lines needed to complete the pattern can be easily seen.

Plate III, Fig. 19, illustrates a pattern much used in perforated stone screens at Fathpur-Sikri. The pattern consists of overlapping octagons, which have to overlap so far that the resulting squares AA and BB are of the same size. To draw the pattern the panel is first divided into squares and the side CD of a square bisected at G and the adjacent side DE at F. GF is then joined and the diagonal of the square CE drawn in. The angle ECD is bisected by the line CH and this line cuts GF at the point J, giving the distance CJ as the approximate radius of the octagon required. The drawing in of the octagons is begun but, if the resulting squares A and B do not turn out to be of exactly the same size, a correction in the size of the octagons is required. This may easily be done by drawing circles round each of the two squares. If the squares are not identical the circles will be found to be of different sizes and a circle of intermediate size should therefore be described. The square drawn in it will be correct and will indicate the size of the desired octagon.

It is noticeable in Saracenic art that if two pattern spaces of identical shape occur together in a pattern, they must be either of identical size or widely different. If, in the present pattern, the small squares were nearly but not quite equal in size the aesthetic effect of the design would be greatly lessened.

Many of the more complicated octagonal patterns include octagons of two sizes. These are related definitely to one another in size and the relation is shown in Fig. 20. Here opposite angles of the large octagon being joined by lines produce an eight-pointed figure, which frequently occurs in these patterns and which may be referred to as the "octagonal star." The small octagon is of such dimension that, if its centre is at A, one of its angles B fits into the space between two points of the octagonal star.

An example of the use of large and small octagons together is shown in Fig. 21. The panel is divided into squares in which are drawn octagons in contact by their sides; these form the large octagons of the pattern and are shown at A in heavy lines. Alternate octagons are omitted by leaving out some of the lines, which are indicated by dots. A small octagon C D F G H J K having its centre at L, one of the angles of the large octagon, is then formed, but only six sides are drawn in, the sides between C and K being omitted. The six sides of other small octagons each having as a centre one corner of a large octagon are then drawn, and a few additional lines, whose position can be easily seen, are all that is needed to complete the pattern as shown at B.

A pattern may be formed by octagonal stars in contact as illustrated in Fig. 22. This pattern occurs in black and white marble inlay in the pavement of the central chamber of the Taj at Agra.

In Fig. 23, a pattern is shown in which octagonal stars are combined with straight lines. It is taken from the wall of the Court of the Lions in the Alhambra, (copied from *The Alhambra* by A. F. Calvert, London, John Lane, pp. 241 and 373). This pattern gives a striking illustration of the care exercised by the Moorish artists in preparing their designs. The space is covered with squares as shown by dotted lines, but only certain of these lines are used to form the pattern and an error is thereby produced necessitating correction. At A is shown an octagonal star the adjacent points of which, at B and C, are of slightly different dimensions. This is a fault, as any one might think that an attempt had been made to draw a symmetrical star and that the attempt had failed. In the next octagonal star in the drawing at D, this fault is corrected, all the eight points have been made the same size and meet the surrounding circle. But now a new error is introduced. The line EF is nearly but not exactly in line with GH, and similarly IK is not exactly in line with LM. The impression is given that the lines were intended to be in line but were inaccurately drawn and so GH and LM and other analogous lines have to be shifted slightly. For this reason therefore the line NO has been drawn parallel to, but off the original construction line in order to bring it into line with PQ, and similar corrections have been made in other parts of the illustration.

The design depicted in Plate IV, Fig. 24, is found in a beautiful white marble trellis-work screen in the tomb of Itimad-ud-Daula in Agra. The pattern includes large and small octagons. The former overlap by two sides and are constructed somewhat differently to similarly overlapping octagons described in a previous paragraph. The panel is covered with squares and the diagonal of one of them, AB, having been drawn, the angle CAB is bisected by the line AD. With the centre at B and with radius BD describe a circle and repeat this circle in equivalent positions as shown in the figure. As indicated by dotted lines, points on the circumferences of the circles are joined, thereby forming large octagons overlapping by two sides as shown at

E. In order to find the size of the small octagon required, prolong the line FG until it meets the dotted line JH at K; JK will be the radius of the small octagon. Similar small octagons are drawn round points similar to J, F and H, and the resulting octagonal stars, M, M, are filled in with a svastika. The completed pattern is shown at L.

In adapting this pattern to marble-work the masons first carved out certain of the sides of the large octagons leaving them in relief while the remainder of the surface of the marble was lowered by about half an inch. Thus was formed the pattern shown at N, which occurs in this form elsewhere, for instance in the Jodh Bai's Palace at Fathpur-Sikri. In the present case, however, the masons wished to use the rest of the original pattern as well but, owing to the thickness of these lines, the space available for the remainder of the design was less in area than in the original drawing. The small octagon was therefore not drawn with its centre at a point corresponding to J, but the part of it included in the pattern-space S was drawn with the centre at P, and that part of it in the pattern-space R had its centre at Q. In order to find the size of the new small octagon required, from the centre S with the distance SP describe a circle and within this circle inscribe an octagon UV. This octagon represents the original large octagon lessened in size to correspond to the new pattern-space. By joining TP and XU the two lines will intersect at W, and PW is the required radius of the small octagon. The completed pattern is shown at Y.

In a perforated stone screen in the vestibule of Akbar's tomb at Sikandra there is a somewhat similar pattern. The screen is of stone painted in red and gold, and is illustrated in Fig. 25. To construct the pattern, the panel is covered with octagons in contact by their sides as indicated by dotted lines, alternate diagonals of each octagon being drawn in and shown by continuous lines. These latter form the principal lines of the pattern, and their arrangement is identical to that of the thickened bars of the pattern just described. As shown in the construction of the previous pattern, they may be regarded as having been formed by parts of large octagons overlapping by two sides, and the original octagons depicted by dotted lines, therefore, correspond to the small octagons. As in the case of the former design, the pattern-space for the small octagons is restricted owing to the greater thickness of the bars, and the small octagons consequently have to be diminished in size. The length of their radius is easily determined by joining DE and bisecting it at A. From the point A at the distance AB describe a circle, which is shown as a dotted line; FC is the required radius of the small octagon. The remaining lines of the pattern consist of octagonal stars with lines connecting them.

The thickened bars of the two preceding patterns make angles, which are obviously similar to those made by the meeting of two sides of an octagon, and hence these patterns may be considered as having been formed from octagons of which only two sides are drawn. A like description applies to the next two patterns shown in Plate V, Figs. 26 and 27. In order to set them

out the space to be decorated is covered with squares. At the corners of each square is drawn a letter X, whose obtuse angles are equal to those of an octagon. This can easily be done by the use of a template cut out in card-board to the shape of an octagon. Whether or not the ancient artists who designed these patterns, used templates is uncertain but, personally, I have found templates of great assistance in discovering the method of constructing Saracenic designs and they would probably also save much labour when designing new patterns. In Figs. 26 and 27 the possible method of utilising octagonal templates is indicated by dotted lines. These two patterns have only been seen by me in the older buildings of Fathpur-Sikri.

3. GEOMETRICAL ARABESQUES.

It will have been seen that the methods required for drawing hexagonal and octagonal patterns are readily discovered, but we now come to a class of patterns that can only be set out by a method that is not immediately apparent. In a previous paragraph I have mentioned the lucky chance by which the clue to their construction lines was discovered.

A very simple design of this class is shown in Plate V, Fig. 28. The construction lines, which are shown as dotted lines, consist of octagons in contact and they must be so arranged that each of the corners of the repeat corresponds to the centre of an octagon. To construct the pattern, two lines must be drawn bisecting each side of each octagon and crossing each other like the letter X. Each of these lines is then prolonged till it meets another pattern line and the octagons having been deleted the pattern is finished. The only doubtful point that arises is in what direction the lines forming the letter X should be drawn. On referring to the illustration it will be seen that the pattern lines AB and CD are in line with one another, and that they pass through the points E and F, which are centres of sides of octagons. These lines also lie parallel to a diameter of the octagon GH. All the other lines of the pattern can be similarly drawn in without difficulty. The construction lines of this pattern consist of octagons with "residual spaces," which are squares. Each octagon gives rise to an eight-pointed star and each square to one with four points.

It is convenient to restrict the description "Geometrical arabesque" to patterns formed in this manner, namely with the help of construction lines consisting of polygons in contact. Apparently nearly every combination of polygons can be made the basis of a geometrical arabesque design provided that the "residual spaces" are fairly symmetrical. The skill of the Arabian artists in discovering suitable combinations of polygons is almost astounding. Bourgoin's work, *Le trait des entrelacs*, contains a large but by no means exhaustive collection of arabesque designs, among which are no less than four different patterns based on combinations of dodecagons, heptagons and 16-gons. There are also two patterns based on 16-gons combined with decagons, and six patterns are based on 14-gons. In other patterns polygons of 15, 18, 20 and 24 sides are used.

The next geometrical arabesque pattern to claim our attention is based on octagons and irregular pentagons, which are shown in thin lines in Fig. 29. It will be seen that the octagons are the basis for eight-pointed and the pentagon for five-pointed stars. To set out the pattern the following procedure should be adopted. In the right-hand half of Fig. 29 the completed pattern is shown, and in the other half—the square ABCD—the construction lines. Each corner of the repeat of the pattern corresponds to the centre of an eight-rayed star, a quarter only of each of which is shown in the figure, and in the square ABCD each corner of the square corresponds to the centre of an octagon, of which again only a quarter of each is drawn. It is necessary that the octagons should be of such a size that the distance from one octagon to the next, XY, is equal to the length of a side of the octagon, as YZ. To find out the required size of the octagon, commence by drawing in the diagonal of the square AD and bisecting the angle BAD by the line EA. On EA then mark off a distance AF equal to one-third of the length of the side of the square AB, and from the point F draw the line FG perpendicular to AE. FG cuts the diagonal at the point H, and AH is the approximate radius of the octagon required. With the drawing in of these octagons, which, with the diagonals of the square, divide the remaining space into irregular pentagons, the primary construction lines are completed. The secondary construction lines, indicated by dotted lines, consist of certain circles, the two diameters of the square and the interradii of the octagons. With each of the corners of the square as centres and radii equal to half the side of the square draw the circles NN, and with the point where the diagonals of the square cut one another as centre describe the circle O in such a manner that it touches the circles N. Then draw in the interradii of the octagons, such as BW and CW.

The first pattern lines to be drawn are JK and LM, which are in line with one another and pass through the points W and W. To find where these lines should end externally draw the line PL, which cuts the circumference of the circle O at two points. One of these points (P) is where the circle is cut by an interradius of the square, and the other is the point where it is cut by a diagonal. The two lines PL and ML end where they meet one another. Then with the centre C and the distance CL describe a circle Q and repeat this circle in the other octagons. All the rays of the eight-pointed stars will end outwardly on these circles Q, Q. For instance the lines RS and TU are drawn in line with one another and end on the circles Q,Q externally and on interradii at R and U internally. The only remaining pattern lines are those required to complete the octagon drawn in the circle O. These lines in each case are prolonged till they meet a star ray on one of the circles Q.

In the two geometrical arabesques just described the repeat was a square; such patterns, therefore, can only be used for panels which are square or which are made up of a number of squares. The pattern in Fig. 29 is drawn with

the lines interlaced, each line passing alternately over and under each line that it meats. Almost all Saracenic geometric designs permit of this treatment, which adds, where suitable, to the aesthetic effect by making the different parts of the pattern more interdependent than they would otherwise appear. That this treatment is possible is due to the fact that in these designs, "dead ends" rarely occur because, as a rule, each line zigzags its way through the pattern till it ends at the margin. Thus each line takes a part in the formation of several pattern-spaces. In a pattern containing many "dead ends" each line only circumscribes one pattern-space and those with which it is immediately contiguous, thus causing the design to look like a number of pieces put together rather than one continuous pattern. In Saracenic art the artists endeavour to decorate a surface by modifying it, rather than by concealing it with struck-on ornamentations. This probably is one reason for their convention that a whole number of repeats of the pattern must be used in a decorated panel.

An interesting example of how arabesque patterns should *not* be drawn is shown in Fig. 29A. The pattern occurs in each of several panels in the ceiling of a room in a large hotel in Bombay. The designer, with misapplied ingenuity, had attempted to make the pattern last described fit a space for which it was quite unsuited and in this attempt made the following mistakes :—The octagonal star A is only partly included in the panel. The general rule being that a symmetrical pattern-space should be complete, or, should it occur along the side of a panel, exactly half of it should be shown; or again, should it occupy the corner of a panel, exactly a quarter of it should appear. In either of these latter cases the eye can easily imagine the rest of the outline and the symmetry of the pattern-space is thus indicated. But in the pattern now under criticism, an irregular fraction of an octagonal star occurs at each corner of the panel. The neighbouring spaces B and E are of a clumsy shape. In designing Saracenic patterns one should endeavour always to provide pattern-spaces that have at least a bilateral symmetry. At E, and at other points in the pattern, a line comes to a sudden end. This should have been avoided as usually in Saracenic art, as remarked above, there should be no "dead ends" of this description, each line running by a zigzag route through the pattern until it reaches the border, though occasionally, as shown in Plate VI, Fig. 30, some of the pattern lines may form closed figures of symmetrical shape. The result of adhering to these elementary rules of design is that each part of the pattern is connected to and dependent on other parts. It is curious how these rules are neglected by Western decorators, who not infrequently will decorate an otherwise beautiful building with a pattern consisting of stencilled dots and dashes recalling a Morse code message rather than an artistic product. To return to our pattern, F is a space that is neither a square nor an octagon, but is suggestive of a failure to draw either of these figures. It is a very general rule that lines crossing one another should be straight, but the lines GL and KM, crossing each other at H, may be described as bent lines. The custom of avoiding bent lines adds to the difficulty of designing Saracenic

patterns but the result, the increased effect of interdependence of the different parts, is well worth the trouble.

The next pattern is based on dodecagons separated by squares, three repeats of the pattern being illustrated in Plate VI, Fig. 30. Each repeat has a dodecagon in the centre and a quarter of a dodecagon in each of the four corners. The dodecagons have to be of such a size that their sides are equal in length to the sides of the squares M, M separating them from each other. The required size of the dodecagon can be discovered by the following simple method :—

In the first rectangle ABCD, draw in the diagonals, which will cross each other at E. Bisect AE at F and BE at J and join AJ and BF. Then bisect the angle EAJ by the line AH, which cuts BF at H. From the point H draw a line HK making an angle of 45 degrees with FH and cutting EF at K. Then EK is the radius of the required dodecagon and FH the radius of the square. These outlines are then drawn in as shown in the upper half of the rectangle and the free points of the squares are joined to the neighbouring free point of the dodecagons by straight lines, thus forming equilateral triangles as illustrated in the next rectangle. As indicated at LLL, make a dot at the centre of each side of each dodecagon, square and triangle. All the pattern lines are drawn through these dots and two lines passing through each dot form a letter X, as shown at MM. The pattern should be commenced by laying a ruler on the dots N and O and drawing lines through these points. The line drawn through N finishes at one end where it reaches the point P, situated on a line ST, which joins the centre of the dodecagon to the centre of one of its sides. Such a line may be termed an "interradius". From the centre of the dodecagon at the distance P describe a circle, shown in dotted outline. All pattern lines entering the dodecagon end at points where this circle is cut by interradii. The other end of the line PN continues to the diagonal of the neighbouring square, from the centre of which and at the distance the point where its diagonal meets the line in question, draw a circle Q. All the other pattern lines entering the square end at points where the diagonal of the square cut the circle. In a like manner is drawn the circle R, having as centre the centre of the irregular hexagonal space. These are repeated in appropriate places throughout the rectangle, thereby obtaining points of origin and completion for nearly all the lines of the pattern. It may be observed that some of the pattern lines form a square and others a dodecagon. Care should be taken that these figures are symmetrical and regular.

In the pattern just described the construction dodecagons were separated by squares, but in the pattern next to be considered, Fig. 31, we shall deal with dodecagons separated by equilateral triangles with residual spaces such as E shaped like a dice-box. As before the repeat is a rectangle whose diagonal makes an angle of 60 degrees with the base. In the first of the three repeats in the figure, BT is a line dividing the rectangle into two equal

parts. From the point C draw the line CD making an angle of 40 degrees with the base BC, and cutting the central line at D. AD is the length of the radius of the required dodecagon. The upper part of this repeat and the adjoining repeat show the separation of the dodecagons by the triangles P, P, P, and the resulting residual spaces E, E of dice-box shape. Each dice-box contains two of the regular heptagons of the pattern, such as G and F in the middle repeat.

Commence the pattern by drawing in one of these heptagons. This is most easily done by drawing a heptagon of the requisite size on a piece of tracing paper, from which the outline of the heptagon here and at other places in the pattern may be pricked through where necessary. Having drawn in one of the heptagons as at F, one of its sides HJ is prolonged to the point K which is near the interradius LM. The distance of K from the interradius should be such that the tri-lobed pattern-space about to be formed has its three lobes as nearly of the same size as possible. With the centre M and the distance MK describe a circle and mark on each side of each of its intersections by interradii points at equal distances therefrom, as K. The four sides of the heptagons that are prolonged will stop at these points. From K draw the line KN, which ends on reaching an interradius of the dodecagon at N. This line, it will be observed, is nearly but not quite parallel to the radius SM, its end N being a little further from the radius SM than is the other end K. With the centre M and the distance MN draw a circle, shown in the figure by a dotted line. All pattern lines similar to KN end on points where this circle is cut by interradii. In other words this circle is of such a size that the ray RNQK of the star is broader centrally than it is peripherally, and in consequence the pattern is not so stiff as would be the case if the sides of the ray were drawn parallel. Stars with parallel rays, I am informed by Captain Creswell, are more frequent in older work.

A slight modification of the pattern is shown in the right-hand bottom corner. It has the same construction lines but the manner of treating the star is slightly different. The method of drawing it can readily be seen and no separate description is required.

It may be noted that in the above pattern each of the three sides of the triangle used in the construction is touched by the point of a heptagon. Should the sides of the heptagons be prolonged from these points, then a regular hexagon would be formed. An illustration of the pattern obtained in this way is to be found in Bourgoin's work (*Le trait des entrelacs*, Fig. 75).

In Plate VII, Fig. 32, a pattern based on decagons and regular pentagons is shown. Here there is a residual space of an irregular hexagonal shape, half of which forms an outline which may be called a "half-hexagon" and is marked out by the letters TUYW. This figure occurs frequently in geometrical arabesque construction lines and generally, as in the present instance, forms a pattern-space shaped somewhat like a blunt arrow-head. The repeat of the pattern we are considering fits a rectangle whose diagonal makes an angle of

36 degrees with one side and 54 degrees with the adjacent side. The outlines of two repeats are shown in the figure. The diagonals of one repeat, AC and BD, cross each other at the centre E. A decagon is required to be drawn round E and quarter decagons will have to occupy each of the four corners of the rectangle. They must be of such a size th-t the distance between any two of them will be equal to the length of one of their sides. To discover the requisite size the following procedure should be adopted :—Bisect AE in F and at the point F draw a line GH perpendicular to AE. Then bisect the angle EAB by the line AL, which will cut GH at the point L. Again, bisect the angle ALH by the line LJ, which will cross AE at M. AM is the radius of the decagon and LM the radius of the required pentagon. On the line FE mark off FK equal to FM. Then MK will be the length of the side of the decagon and also of the side of the pentagon. With these data the decagons and pentagons may be drawn as depicted in the u-per part of the repeat.

To construct the pattern commence by placing the ruler in position for drawing a line from N to O, and draw in the lines NT and OP. These two lines terminate near the centre at the points T and P where they meet interradii of the decagon. Then with the centre E and the distance ET draw the circle shown in dotted outline. All pattern lines entering the decagon must end on this circle at points where it is cut by interradii, which latter have now to be drawn in. The lines drawn from the point P cross the centres of sides of the decagon at O and V, and on being prolonged, cut radii (not interradii) of neighbouring pentagons, as at Q. With the centre of this pentagon and the distance Q describe a circle, on which all pattern lines entering the pentagon will end at points where it is cut by radii. It should be observed that PQ is in line with RS. If the circles in other pentagons are repeated, the points of origin and ending for each of the pattern lines will then be obtained, except in the case of some of the lines that enter the "elongated hexagon." The position of these is readily found, however, by drawing parallel to OP the line XZ which will end within the hexagon where it meets the line coming from the neighbouring pentagon.

In earlier Saracenic work the pattern is drawn as described above, but, in later work lines such as OP and XZ are not drawn exactly parallel but approach each other outwardly. This variant of the pattern, so far as my experience of it goes, is that met with in India.

An allied pattern is shown in Fig. 33. It may be found, carved in relief, in the border of a large stone panel in Birbal's House at Fathpur-Sikri. As the pattern has a width at the sides different from that at the top and bottom, it is but badly suited for a border and the designer deserves congratulation on his ingenuity rather than on his success. The construction lines consist of halves of decagons, of "half-hexagons" and of regular pentagons. In addition there are some triangular spaces, each of which is equal to the triangle that would be formed by drawing lines from two angles

of a decagon to its centre. The pattern should be begun by drawing the lines that pass through the centres of the sides of the half-hexagon. The position of the remaining lines is easily found.

At the entrance to the large mosque at Fathpur-Sikri is a mosaic panel consisting of marble pattern-pieces let into red sandstone. The design, illustrated in Fig. 34, is based on a fourteen-sided figure that may conveniently be designated a "14-gon." Each 14-gon is separated from neighbouring 14-gons by squares. Certain radii of the 14-gon are prolonged and form irregular pentagons (such as M) and a "residual space" L having the form of an elongated hexagon. The repeat of this pattern requires a rectangle whose diagonal CB makes an angle with the base CD of fifty-one and four-sevenths degrees. This angle is the seventh part of 360 degrees. To find the required size of the 14-gon proceed as follows:—EF is the vertical line dividing the rectangle into two equal parts, and the centre of the rectangle is at J. Divide the angle CJF into three equal parts by the lines GJ and HJ. From the point D draw the line DK at an angle of 27 degrees with the base CD. This line intersects JG in K, and JK is approximately the required radius of the 14-gon. The exact size can be readily obtained by trial and error, it being required that the length of a side of the square shall be equal to the length of a side of the 14-gon.

Having drawn in the primary construction lines, the pattern should be commenced by drawing the line NO which passes through the centres of two sides of the elongated hexagon. This line ends at N where it meets the radius of the pentagon M. As the pentagon is irregular the position of its centre must be chosen arbitrarily. With the point chosen as centre and at the distance N, describe a circle. All pattern lines that enter the pentagon will end on this circle at points where it is intersected by its radii. The second pattern line to draw is NP. This passes from the point N through the central point of the adjacent side of a 14-gon and ends when it reaches an interradius of the latter figure at P. Then with the centre J and distance JP describe a circle. All pattern lines that enter the 14-gon end on this circle at points of intersection with interradii. The circles being repeated in each pentagon and 14-gon the remaining construction is simple.

Plate VIII, Fig. 35, illustrates another 14-gon design, but this time the 14-gons are separated by heptagons, occurring in pairs. The heptagons of each pair overlap each other by two sides. The repeat requires a rectangle whose diagonal makes an angle with the base of fifty-one and three-sevenths degrees and may be obtained in the following way. Draw the horizontal line AB and the vertical line AC. At a convenient distance, as C, draw another horizontal line CD. With the centre A describe the arc EF, which, in order to diminish errors in measurement, should be as large as possible, and divide the arc into seven equal parts. Mark off these parts by lines drawn from the arc to the point A, as indicated in the figure and numbered 1 to 6. Line 3 is continued till it reaches the upper horizontal

line at D. Then CD is the width of the rectangle required. GH is a line drawn horizontally through the centre of the rectangle and line No. 1 cuts it at J. GJ is the radius of the 14-gon required. The centre of the construction heptagon is at the point Y, which is obtained by prolonging the interradius GX till it cuts AC. The heptagon is of such a size that the length of any one of its sides is equal to the length of the side of the 14-gon. Describe a circle around the centre of each heptagon of such dimension that it touches the circle drawn in the neighbouring heptagon as at the point H; then draw in the radii and interradii of the heptagon. In each heptagon a seven-pointed star is required. All the lines forming this star will pass through points of intersection of the circle H with radii as indicated at M and W.

Commence the pattern by drawing the lines N and W in line with one another. These two lines end centrally at points where they reach interradii of the heptagon. The limit of their outer ends may be left undetermined for the moment. Two other lines of the star similarly in line with one another and ending internally at similar points are drawn at H and M. The remaining lines of the star are put in in the same manner and need no further description. It will be seen that the 14-gons and heptagons leave residual spaces of a dice-box shape, such as KL and each dice-box has to contain two pattern heptagons, which should be drawn in. Prolong one of the sides of the pattern heptagon into the construction heptagon as far as the point P, where it meets the line M of the star. Now with the centre of the construction heptagon and the distance P describe a circle. All the lines of the seven-pointed star will terminate outwardly on this circle. Prolong another side of the pattern heptagon into the neighbouring 14-gon till it reaches the point R, which is situated near an interradius. With the centre C and the distance CR describe a circle and mark off on it points equidistant from each interradius as R is distant from an interradius, such as V, V. These points limit the outer ends of the pattern lines that make the 14-rayed star which occupies the 14-gon. From R draw RT nearly but not quite parallel to SC, the point T being on an interradius. With the centre C and the distance CT describe a circle. All lines of the star will terminate centrally on this circle where it is intersected by interradii. When completing the pattern it is convenient to draw a heptagon of a size to fit the dice-box outline on a separate piece of paper and to transfer it to tracing paper: then with the help of the latter each of the pattern heptagons can easily be drawn in.

In the pattern just described twinned heptagons fit exactly a 14-gon figure. We will now consider a pattern, in which twinned heptagons are applied at intervals to the circumference of a 16-gon, to which figure they do not fit exactly. In the construction lines are also included dodecagons. The rectangle required for the repeat of this pattern is a square. The first step is to find the requisite size of the various construction polygons employed. This may be done by the following method, which is illustrated in Fig. 36. The letter A marks the centre of the repeat. Divide the angle

BAC into four equal parts, and prolong the line forming the uppermost of these parts till it meets the side of the square at D. Then D is the centre of the heptagon. With the centre D and any radius describe the semicircle EE, and divide its circumference into seven equal parts as shown by dotted lines leading to the centre D. One of these lines DF cuts the horizontal line AC in F. Then AF is the radius of the required 16-gon and DF that of the heptagon. Continuing, mark off CG equal to CD: and G then is the centre of the second heptagon. Draw in these heptagons and those in corresponding positions on each of the other three sides of the square. Along the diagonal (AX) of the square mark off AT equal to AF, and join the point T to angles of the neighbouring heptagons. By repeating this construction along the other diagonals the 16-gon is completed. It will be seen, however, that the sides of the 16-gon thus obtained are not all quite of equal lengths, a fact that will have to be allowed for when the drawing in of the pattern is begun. A quarter of a dodecagon is shown occupying each of the four corners of the square. It is constructed by marking off the point U on the diagonal at an equal distance from the centre X as the point W on the heptagon already drawn. By joining U to the neighbouring heptagons the quarter dodecagon is completed.

To make the pattern, commence by drawing one of the pattern heptagons that occupy the dice-box-shaped residual spaces, as at H, and prolong two of its sides to the points J and K. As in the previous figure (Fig. 35) it is convenient to draw this heptagon with its prolonged sides, in the first instance, on another piece of paper and to transfer it to tracing paper. The tracing is then placed on the dice-box outline in such a position that one angle of the heptagon coincides with the point Z, which is the centre of a side of the construction heptagon whose centre is at G. Then the tracing is rotated a little to and fro until the lines J and K are equidistant from the adjacent sides of the polygons over which they are lying. The point J is then pricked through near the interradius AY and K is pricked through near the interradius of the corner dodecagon. With the centre A and the distance AJ describe the circle S. All the outer ends of the rays of the 16-pointed star about to be drawn will end outwardly on this circle. Now a difficulty occurs in that the sides of the 16-gon are not of equal length as already pointed out. Hence if the rays of the star were oriented on the interradii, they would be of unequal width or would appear to be at unequal distances from each other. It is therefore advisable to repeat the circle S on another piece of paper, and to divide the circumference into 16 equal parts. A pair of dots corresponding to each of the 16 divisions is then marked on the circumference. A second smaller circle for limiting the inner ends of the rays is also described and likewise divided into 16 equal parts, the divisions being also marked by dots. Both these sets of dots are then transferred to tracing paper and by its means can be pricked through in their correct positions on the drawing. The lines forming the rays of the star are drawn in to these dots and thus the rays are made of equal breadth and are equidistant.

A seven-pointed star is now required to be drawn in each construction heptagon. Commence by describing in each heptagon a circle of such a size that it touches a similar circle in the neighbouring heptagon. Each of the lines forming the star will have to pass through a point of intersection of a radius of the heptagon with this circle, and they have to be drawn parallel to an adjacent interradius. For instance NO and LM are each parallel to the interradius PR. Centrally all these lines terminate where they meet a radius, and externally either where they meet lines coming from the dots on the 16-gon circle, as indicated in the line finishing at L, or where they meet lines formed by prolongation of the sides of the small pattern heptagons.

The pattern shown in Plate IX, Fig. 36A, has the same main construction lines as the preceding one, but the drawing of the pattern is carried out in a very different way. In all previously described geometrical arabesques, a pair of pattern lines forming a letter X crossed the centre of each side of each polygon. In the pattern now to be considered two X's occur on each of the sides of each polygon and pass through the two points formed by dividing the sides into three equal parts. The pattern lines pass through the points thus obtained.

Commence the pattern by drawing a seven-pointed star in each construction heptagon. The star consists, not of parallel rays, but of overlapping trianguloid figures. The easiest way to draw these is to make in each heptagon a smaller heptagon (such as A and B). The dimensions of these smaller heptagons are such that one side is common to both, as FM. Each side of the small heptagon is divided into three parts by points such as C, D, E and F. The parts thus marked out are not quite equal, the central part being made a little larger than its neighbours. Begin the star by drawing EH in line with the points E and C and ending at H, this being the point where it meets a radius of the small heptagon. With the centre of the heptagon and the distance H describe a circle. All the inner ends of the pattern lines lying inside the small heptagon end on this circle at points where it is intersected by radii, as at H. The outer ends of the lines terminate at the points already marked out on the sides of the small heptagon, such as at E and F. To complete the trianguloid figures lines are drawn from the points just mentioned, and from similar points, through the points of division of the sides of neighbouring polygons, such as at J and K.

The lines forming the rays of the 16-pointed star of the 16-gon, instead of being drawn straight as more usual, are shown as curved. Bourgoin's works contain many examples of curvilinear geometrical arabesque patterns formed by replacing some or all of the straight lines by curves. As the pattern here illustrated was drawn by me from memory, it is possible that it does not exactly represent the original. But when dealing with curves there is plenty of room for variety of treatment.

This combination of 16-gon, dodecagon and twinned heptagons appears to have been popular with the Arabian artists. Patterns drawn on this basis are shown in Plates 131 to 135 inclusive of Burgoin's *Le trait des entrelacs.*

We will now consider an example of a widely used class of patterns based on decagons combined with spindle-shaped figures, the latter being derived from decagons. For instance the spindle-shaped outline CH in Plate IX, Fig. 37, may be drawn with the assistance of a template cut out in cardboard to the shape of a decagon. When placed in the position indicated by the letters F,G,H,J,K,L,O, the sides CF, FG and GH of the spindle, may be drawn in. The template is then shifted so that the point J coincides with H and the point O with C. Then the remaining sides of the spindle namely HM, MN and NC can also be drawn in. The draftsman will probably find it more convenient to draw the decagon on tracing paper and after placing it in the necessary positions to prick through at its angles with a needle. To find the size of the decagon, the following very simple procedure suffices:—The diagonal AB of the repeat of this pattern makes an angle with the vertical side of one-fifth of a right angle, or 18 degrees. Divide the angle at A into five equal parts, which are indicated in the figure by dotted lines. The upper one of these lines, AC, cuts the central vertical line at the point C. AC then is the radius of the decagon required.

The pattern is easily constructed by drawing a pair of lines through the centres of each side of each polygon. It will be noted that the pattern lines form pentagons such as C, N and H, and, as it is necessary that they should be quite regular, the best method of achieving this is by drawing circles in contact, as shown at E,E, taking care that the crossings of the pattern lines take place on the circumferences at equidistant points. In the construction, decagons, whose centres coincide with the corners of the repeat, and of which, accordingly, quarters only are drawn, star-shaped figures of the usual kind are shown. A similar star might be drawn in the decagon at the centre of the repeat but, instead, a different treatment has been adopted. Each of the pattern lines that enters the central decagon is continued, in the first instance, only till it meets a radius. A space, in which a pentagon surrounded by small lozenge-shaped figures has to be drawn, is thereby obtained. This pentagon should be made the same size as other pentagons of the pattern. By prolonging its sides and also the sides of neighbouring pentagons the lozenge-shaped figures are produced.

The pattern shown in Fig. 38, is to be found on the soffit of an arch in the Hakim's bath at Fathpur-Sikri. It is a most unusual design in that it contains eleven-pointed stars. One may wonder what can have stimulated the artist to design a pattern so difficult to draw, and one that the ordinary observer could not easily distinguish from other patterns more easily set out, and which, from its nature, most inevitably have lacked the symmetry that Muhammadan artists aimed at in their work. On the margin of a rough copy of this pattern, that I made more than twenty years ago, are some partly obliterated notes describing a method of drawing it that I appear to have discovered. It is unlikely, however, that this was the method used by the original artist, it being more probable that he drew in the pattern roughly

with the assistance of ordinary construction lines and then rectified it by freehand. Nevertheless as a curiosity it may be permissible to describe my method in so far as it can be deciphered.

The notes say:—"Make a dodecagonal template whose diagonal is equal in length to one-third the width of the panel. Pin it down at its centre and draw in the sides A and B (as shown in the outline at the side of Fig. 38). Rotate it through half the central angle C and draw in the sides D, E and F. Rotate the template through a quarter angle and draw in the side G. Then (presumably after returning it to a neutral position) rotate through a quarter angle in the other direction and draw in H. Join the ends of these sides, thereby making an irregular 11-gon which may be cut out in cardboard and used as a template. Thus is drawn the construction outline for the group of four eleven-rayed stars that occupy the centre of the repeat. Also make a template from a regular decagon, the length of whose side is equal to that of the side of the dodecagon originally used. This template is used to mark out the radii (not the sides) of the eight-rayed figure Z. The construction is seen to include several spindle-shaped figures similar to those made by overlapping decagons. The sides of the spindles K and L are respectively equal in length to the short and long sides of the 11-gon. The sides O, P, Q and R are drawn by means of the decagonal template. From the centre M at distance N describe a regular dodecagon. Commence the pattern by drawing a line such as ST. This passes through the centres of adjacent sides of the 11-gon and of a side of a spindle-outline. The intersection of this line with an interradius of the 11-gon at S indicates the size of the circle required for drawing the remaining parts of the 11-rayed stars." On drawing the pattern by this method a certain amount of freehand rectification will be found necessary, but not so much as would be the case if the above directions are not followed.

Another example of singular ingenuity is presented by the pattern illustrated in Plate X, Fig. 39, which is peculiar in that it contains fifteen-rayed stars. The construction lines are easy to draw. A dodecagon is placed at the centre and is surrounded by six 15-gons, which will be found to fit very well. The length of the sides of the 15-gon and of the 12-gon are equal and the dodecagon is separated from the surrounding 15-gons by triangles. The remaining residual spaces are dice-box outlines and triangles. In making the pattern, letter X's have, as usual, to be drawn through the centres of each side of each of the "gons." A pattern line in no instance crosses two of these centres and hence the directions of these lines must be a matter of guess work. But the guessing is easy and there is no special difficulty in drawing the pattern. The design is taken from Bourgoin (*Le trait des entrelacs*, Plate 128).

Much ingenuity is also shown in the construction of the pattern illustrated in Fig. 40. The construction lines are made from 18-gons and dodecagons, which are first drawn in such a way that alternate pairs of sides of the dodecagon are overlapped by pairs of sides of the 18-gon, leaving

residual spaces of dice-box shape. Half-hexagons, whose size must be guessed, are now drawn in contact with those sides of the dodecagon and the 18-gon that abut on the dice-box outline. The overlapping sides of the polygons are not required and where they occur their place is taken up by two irregular pentagons. Commence the pattern by drawing one of the heptagons that fit into the dice-box outline and prolong certain sides of this heptagon to points near the interradii of the large polygons. These points indicate radii of circles that should be drawn in to limit the length of the 12-rayed and 18-rayed stars of the pattern. The unsymmetrical construction pentagon leads to an irregular five-pointed star, and this may give some trouble when drawing in, as its lack of symmetry must be veiled as much as possible.

Plate XI, Fig. 41, shows a pattern that includes seven-rayed stars. It is a peculiar pattern because the repeat is not a rectangle, as is usual, but a rhomboid. Along the long side of the rhomboid the repeat is reversed, and hence, when looked at with the long sides of the rhomboids in a horizontal position, each repeat appears as the looking-glass reflection of its neighbours above and below. This pattern is drawn with the help of slightly overlapping heptagons grouped in fours round a square space, and is a somewhat confusing one to construct. It is from Bourgoin, Plate 170. A curvilinear design on the same construction lines and much easier to draw is given in Bourgoin's *Le trait des entrelacs,* coloured plate No. III. It is taken from the mosque of Sultan Kait Bey (1467-1495).

A singular example of the skill and ingenuity of the Moorish artists is shown in the pattern drawn in Fig. 42. Commence by dividing the angle ABC into four equal parts as indicated by dotted lines. Two of these lines, BD and BE, are used in the next stage of the construction. One of them, BD, meets the line CS at D. D is the centre of an octagon, of which four sides only will be drawn. To find the radius of this incomplete octagon, draw from D eight lines making equal angles with each other, one of which, DE, meets the line BE at E. DE is the radius of the incomplete octagon. Draw in four of its sides as shown, and produce one of the radii, DF, to G. From G mark off GH equal in length to DE, and with the point H as centre draw an octagon with radius HG. Make AJ and AK equal in length to AH, and round the points J and K describe similar octagons. Join the adjacent sides of these octagons by lines such as QR and OP. The result of this construction is that the point D now lies in an irregular heptagon, which should be repeated at N, L and M. An octagon of the same size as the others is then drawn round the point A. The remaining construction lines need no detailed description. The side of the 16-gon (a quarter of which occupies each corner of the repeat) is of such length that the sides of the rays of the 16-rayed star are nearly parallel. This is achieved by making the side UT of the 16-gon equal or approximately equal to FG. Having made these construction lines the actual drawing of the pattern is quite simple. Each octagon is the basis of an eight-pointed star, whose rays are made by lines parallel to one another.

The original pattern, from which that just described was evolved, appears to have been one, in which there was a quarter of a sixteen-rayed star at each corner of the repeat and a complete 16-rayed star at its centre A. The octagons D and L were complete and the space between them was occupied by elongated hexagons and the octagons J, H and K did not exist at all.

4. FLORAL ARABESQUES.

The straight lines of a geometrical arabesque pattern can be replaced, in many instances, by curved lines with improvement to the aesthetic effect. Probably very many of the more complicated curvilinear or floral arabesque designs have as basis a straight line pattern. Bourgoin points out one instance of this and my good fortune led me to discover another.

Plate XII, Fig. 43, is copied from Bourgoin (*Les éléments de l'Art Arabe : le trait des entrelacs,* coloured plate No. IX) with an indication of the geometrical pattern, on which it is based, added. Plate XII, Fig. 44, copied from Bourgoin (*Les Arts Arabes,* Plate 44) presents a design from an inlaid marble in the Gismah mosque in Cairo. It is based on the arabesque pattern illustrated in Plate VI, Fig. 30. Bourgoin also gives two modifications of this pattern in Plate 50. In one of these, with great skill the Arab artists have squeezed and modified the design so as to make it fit a circular space.

5. DECORATION OF DOMES.

The Muhammadan artists in Fathpur-Sikri were wonderfully successful in drawing patterns on curved surfaces and in making them fit a surface such as that presented by the interior of a dome. Take for instance an octagonal room surmounted by a dome, and supposing that on each of the eight sides of the room is an arch which takes its part in supporting the dome, then it usually happens that the triangular space, or double spandril, between adjacent arches is continued upwards in the form of a pendentive into the inner surface of the dome. This being the case, a geometrical arabesque pattern will fit such a space if (1) the apex of the interior of the dome and (2) the apex of each of the eight arches are all occupied by centres of stars of the pattern. This end is achieved in the following very ingenious manner.

Take a decagon, A, in Plate XIII, Fig. 45a, and draw in the ten radii as shown. The surface of the decagon has now been divided into ten triangles of similar shape. Now cut out the decagon in paper and again cut out and discard two of the triangles as shown in Fig. 45b. If the cut edges CD and CE are joined together, the piece of paper will be bent up into the shape of a cone divided into eight equal triangles. As these eight triangles have been derived from a decagon, each is of a suitable shape for fitting into it a decagonal pattern. It is in fact easy to design a decagonal pattern having

three star-shaped spaces, whose centres coincide with the three angles of each triangle. The builders of Fathpur-Sikri, as a rule, made the interior of their domes of such a curve as to correspond with a cone made in the manner just described. Hence we find the interiors of domes supported on square or octagonal bases ornamented successfully with decagonal patterns. As an example Fig. 46 presents a pattern executed on a triangular area equal to one-eighth of a domed surface. At the top, near the apex, the construction lines include three of the spindle-shaped figures that were described previously as being formed by the overlapping of decagons. Then below follow five decagons in contact, and in the spandril space another spindle. With the aid of these construction lines a symmetrical decagonal pattern is easily drawn.

Another example of dome decoration is shown in Fig. 47. The construction lines consist of a series of decagons in contact with dice-box outlines as "residual spaces," and near the apex of the dome spindle outlines are also introduced. The actual drawing is quite simple as many of the lines of the pattern cross through central points of two construction lines and thus have their direction fixed at once without having recourse to further measurements.

Fig. 48 shows the decoration of the interior of the two half domes in the Agra Gateway in the outside wall of Fathpur-Sikri. The construction lines consist mainly of overlapping decagons. Near the lower margin of the pattern is shown a complete decagon, which by ordinary treatment should produce a decagonal star, but, by leaving out parts of the star (as indicated by dotted lines), space is found for a pentagon surrounded by five small lozenge-shaped figures. This type of pattern has been explained in detail in the description of Fig. 37.

In the instances of dome decoration above described, the curve of the dome was such that it resembled a cone made from eight decagonal triangles. It may, however, happen that the dome is of that shape above but is steeper below. Should this be the case the surface to be decorated will not resemble the above cone, but will be more similar to a shape formed from the outline shown in Fig. 49a. This is derived from the original construction, but from each triangle a small piece has been cut out from each angle at the base. If the outline is cut out, on bringing the cut edges together, the upper part of the cone will have the same degree of curvature as before, but the lower part will be steeper. Supposing the design employed includes stars of ten rays as indicated by the small circles in Fig. 49b, then, owing to the cutting out of part of the area on which the star is drawn, it may happen that exactly one ray of the ten-rayed star is lost. Thus the completed design will be found to contain nine-rayed stars, though it has been constructed on a decagonal basis.

An example is shown in Fig. 50. In the figure the point A is at the centre of a decagonal star, of which only four-and-a-half rays are drawn. It is obvious that, if another similar figure is placed next to this one so that the edge AB coincides with its counterpart, another four-and-a-half rays

will be added, making a total of nine. Thus we shall find in the pattern a nine-rayed star built on a decagonal basis. This particular pattern occurs on the interior of the small dome surmounting the Hiran Minar at Fathpur-Sikri.

I have now described one direction in which dome decoration evolved, namely in the gradually increasing complexity of geometrical patterns drawn on a smooth surface. But at the same time evolution was proceeding in another direction. In the Hakim's Bath at Fathpur-Sikri are instances where a single star of an arabesque pattern occupies the whole of the interior of the dome. In this case the surface is not smooth but the lines of the rays of the star stand out, the plaster being carved away from each side of them. The next stage introduces dome decoration based on a pattern containing several stars. In the older examples the star-centre is always horizontal, and the points of the star are connected to other star centres by the pattern lines sculptured out in relief. Examples of this stage are visible in a ruin known as the Gara-durji-ka-makan at the base of the west side of the Fathpur-Sikri hill. In slightly later examples the star centre is not horizontal but somewhat inclined. In still later examples the slope is more pronounced until at last the star centres lie completely in the same plane as the rest of the domed surface, and, at the same time, are increased in number. All trace of the original conventional pattern is then lost. The star centres, often simplified in shape, become merely points from which lines are drawn to other similar points. Thus at length, by the gradual decadence of the geometrical habit of the pattern, we arrive at the so-called "cobweb" designs found in the half domes of the Taj Mahal and its surrounding buildings.

My best thanks are due to Mr. J. F. Blakiston, Superintendent, Archæological Survey of India, Muhammadan and British Monuments, Northern Circle, for affording me facilities in preparing this paper and also to Fazluddin, Draftsman in the Archæological office, for the great skill with which he has either touched up or made fair copies of my somewhat rough drawings.

E. H. Hankin.

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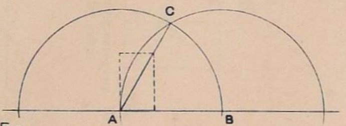

FIG. 1

Oblong of 60 degrees.

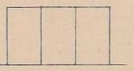

FIG. 2

Panel suitable for three repeats of 60 degree oblongs.

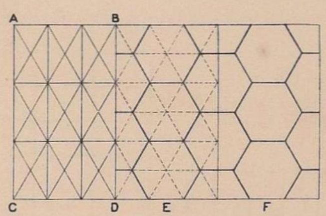

FIG. 3

Pattern of hexagons in contact.

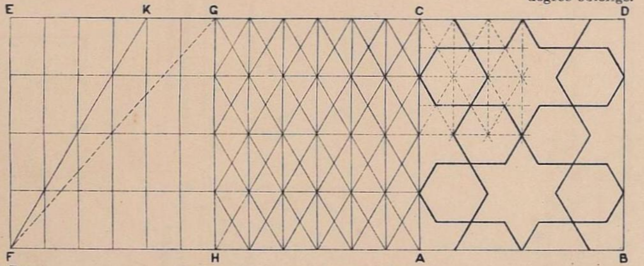

FIG. 4

Pattern of six-rayed stars and hexagons.

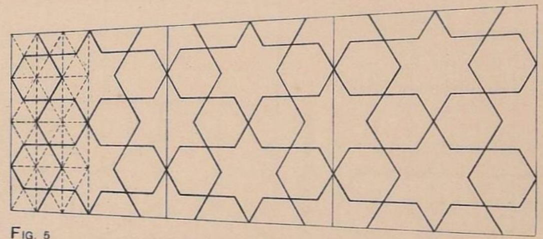

FIG. 5

Pattern drawn in perspective.

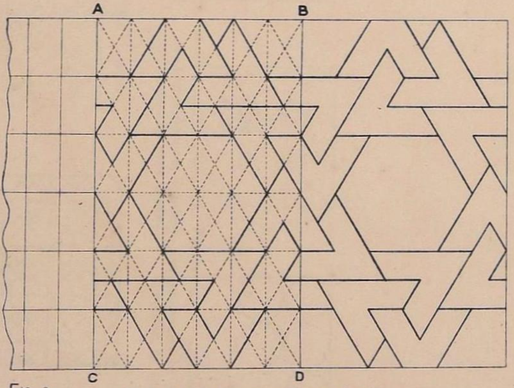

FIG. 6

Pattern of hexagons and arrow-heads.

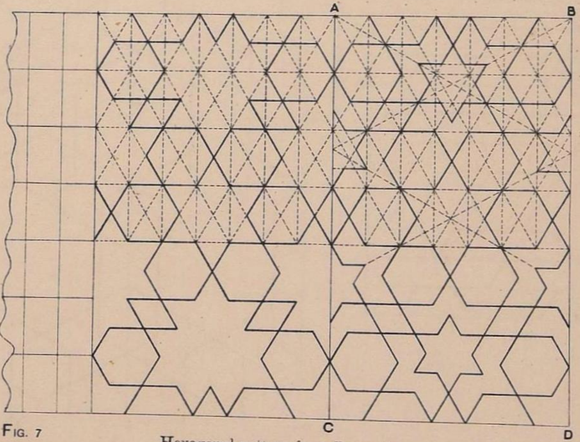

FIG. 7

Hexagonal pattern from Bourgoin.

PLATE I.

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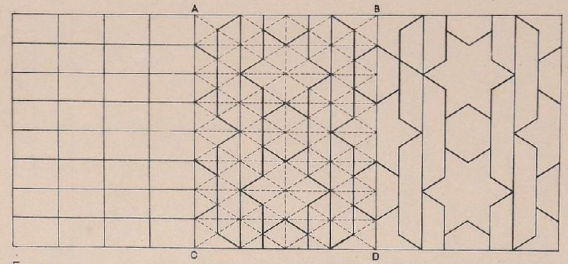

FIG. 8 Hexagonal pattern from a tomb near Delhi.

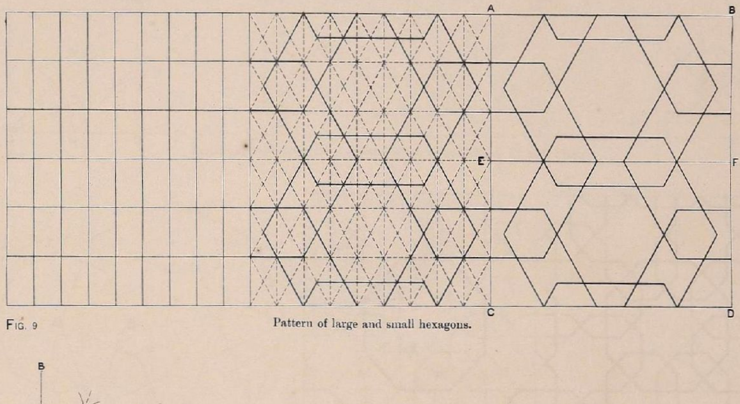

FIG. 9 Pattern of large and small hexagons.

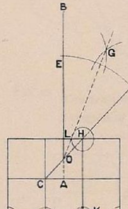

FIG. 10 Method of drawing octagons in contact by sides.

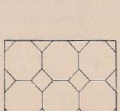

FIG. 11 Pattern formed by octagons in contact by sides.

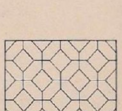

FIG. 12 Pattern of superposed octagons.

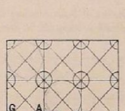

FIG. 13 Method of drawing octagons in contact by their angles.

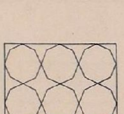

FIG. 14 Pattern formed by octagons in contact by angles.

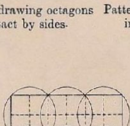

FIG. 15 Method of drawing overlapping octagons.

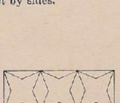

FIG. 16 Pattern of octagons overlapping by two sides.

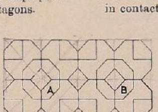

FIG. 17 Method of drawing pattern of Fig. 18.

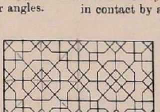

FIG. 18 Pattern derived from octagons in contact.

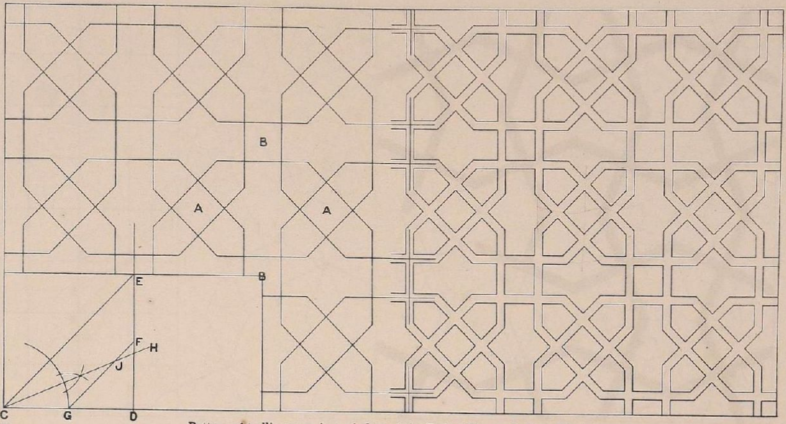

FIG. 19 Pattern of trellis screen in a window of the Dafter Khana, Fathpur-Sikri.

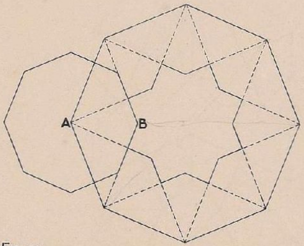

FIG. 20 Construction of an octagonal star and octagons of two sizes as frequently found together in octagonal patterns.

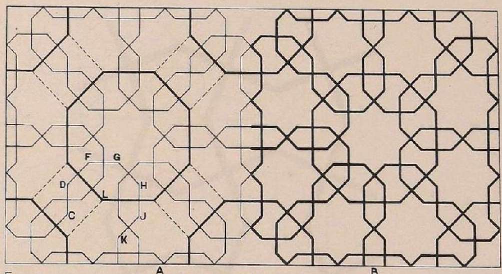

FIG. 21 Octagonal pattern used in inlaid marble in the tomb of Itimadu-d Daula, Agra.

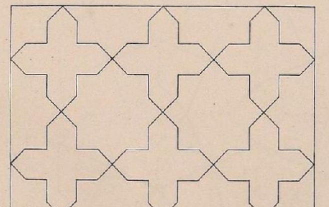

FIG. 22 Pattern of pavement in the central chamber of the Taj Mahal.

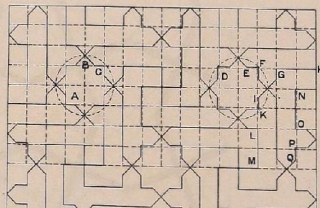

FIG. 23 Pattern from the Court of the Lions in the Alhambra.

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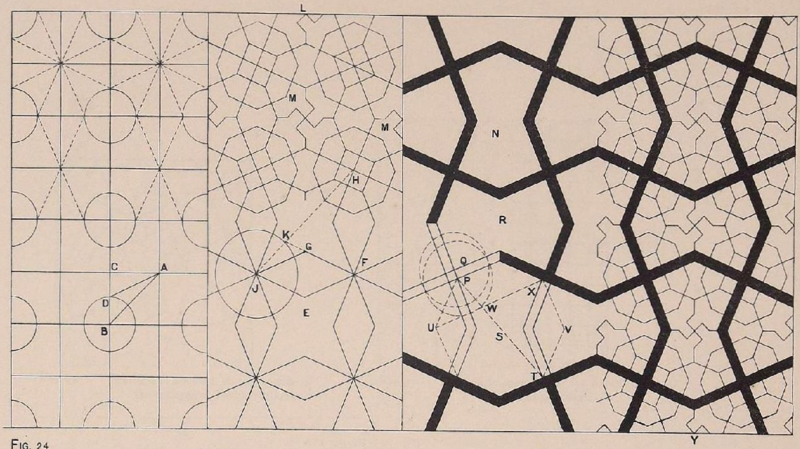

FIG. 24

Pattern derived from overlapping octagons, from the screen in the tomb of Itimadu-d Daula, Agra.

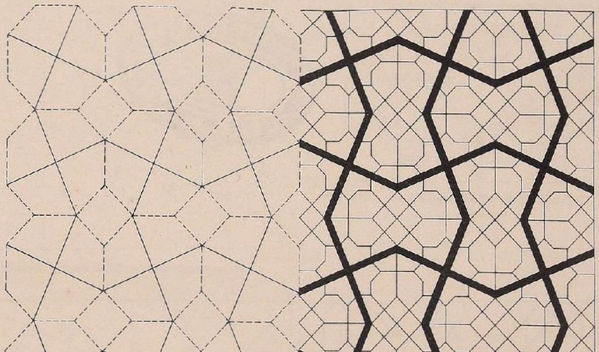

FIG. 25

Pattern derived from octagons in contact, from the vestibule of Akbar's tomb at Sikandrah.

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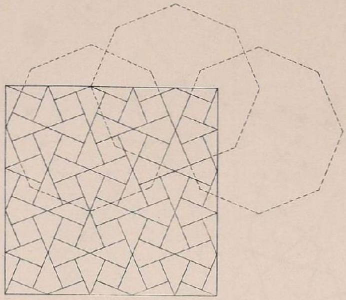

FIG. 26 Pattern of a screen on the outside of the mosque at Fathpur-Sikri.

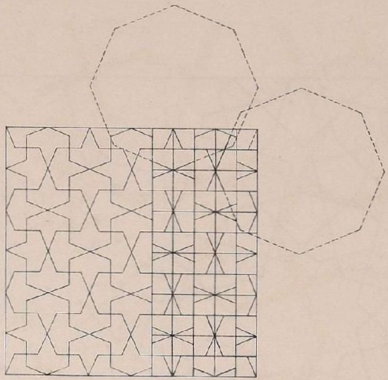

FIG. 27 Pattern in room under the Khwabgah at Fathpur-Sikri.

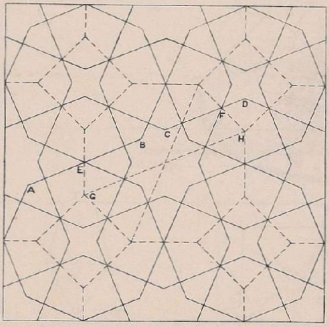

FIG. 28

Arabesque pattern based on octagons in contact.

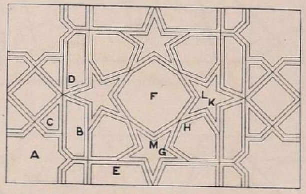

FIG. 29A Design from the Taj Mahal Hotel, Bombay.

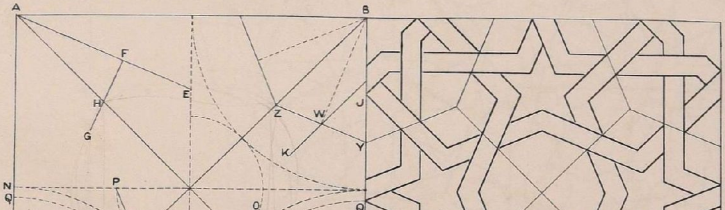

FIG. 29

Arabesque pattern based on octagons and irregular pentagons.

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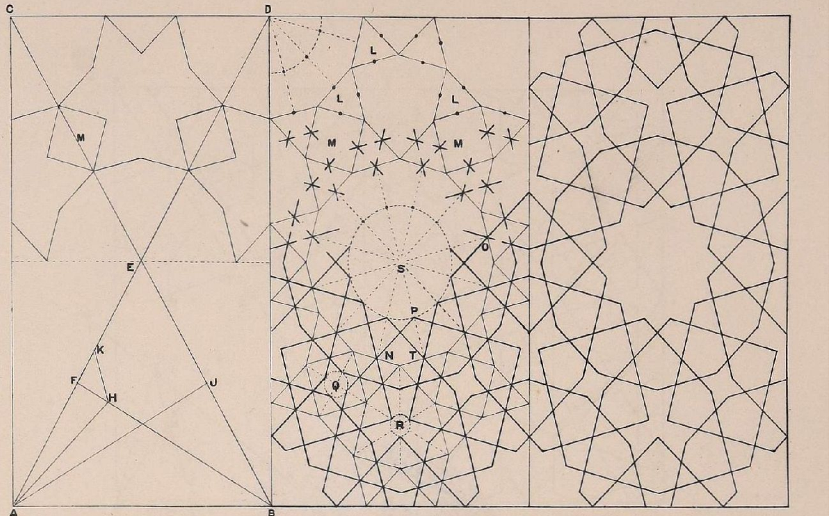

FIG. 30 Arabesque pattern based on dodecagons, squares and equilateral triangles.

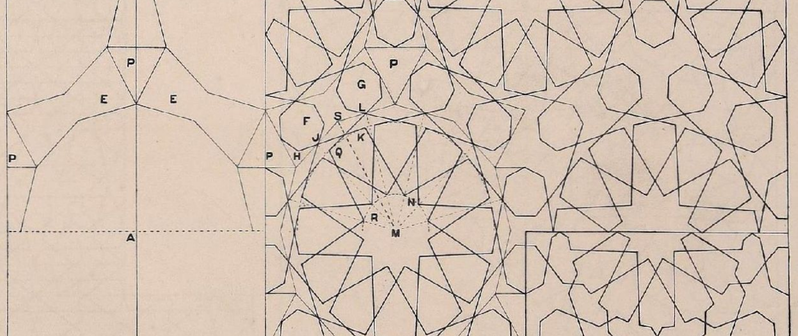

FIG. 31 Pattern bassed on dodecagons separated by equilateral triangles.

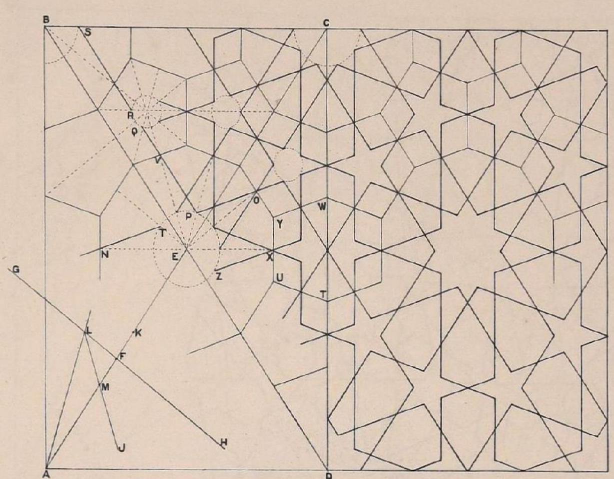

FIG. 32 Arabesque pattern based on decagons and pentagons.

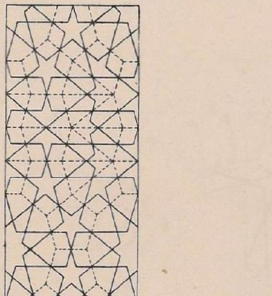

FIG. 33 Border of large panel in Birbal's house at Fathpur-Sikri.

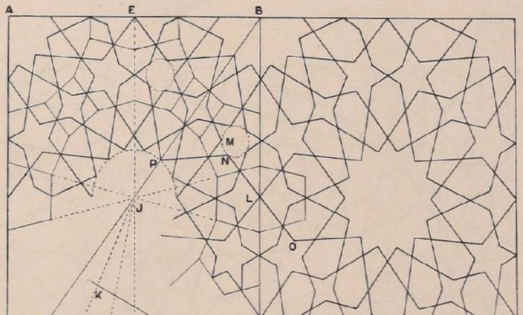

FIG. 34 Arabesque pattern based on a 14-gon, from the entrance to the mosque in Fathpur-Sikri.

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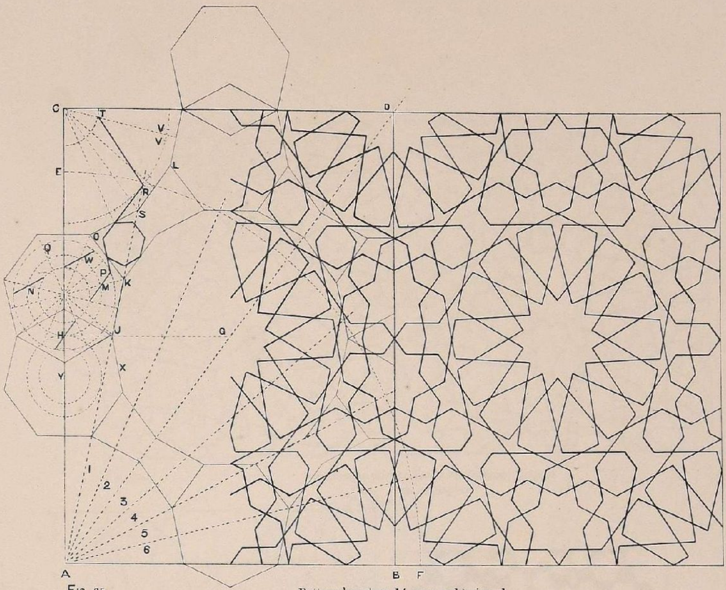

FIG. 35

Pattern based on 14-gons and twinned heptagons.

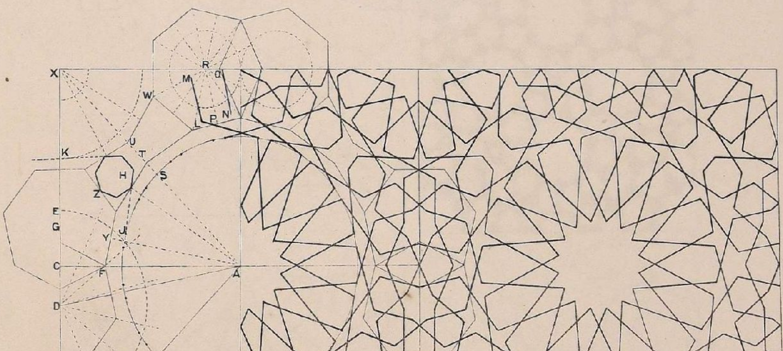

FIG. 36

Arabesque pattern based on 16-gons, 12-gons and heptagons.

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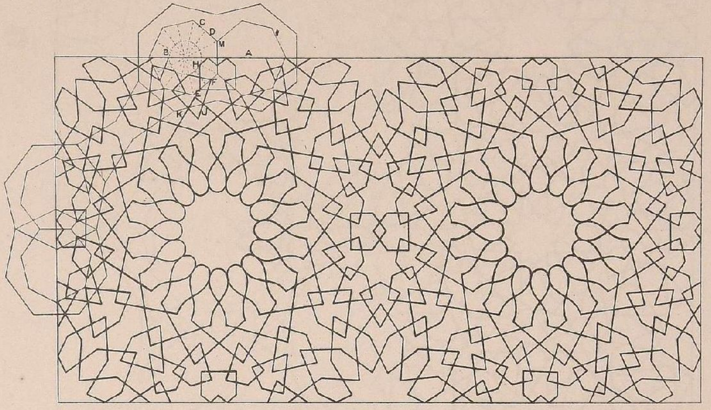

FIG. 36A Arabesque pattern based on 16-gons, 12-gons and heptagons.

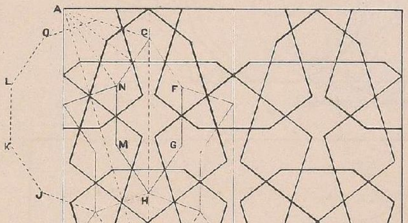

FIG. 37 Arabesque pattern based on decagons and spindleshaped figures.

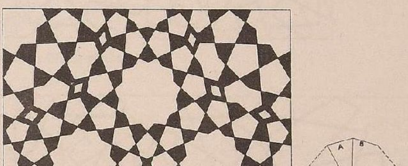

FIG. 38 Pattern from the soffit of an arch in the Hakim's bath at Fathpur-Sikri.

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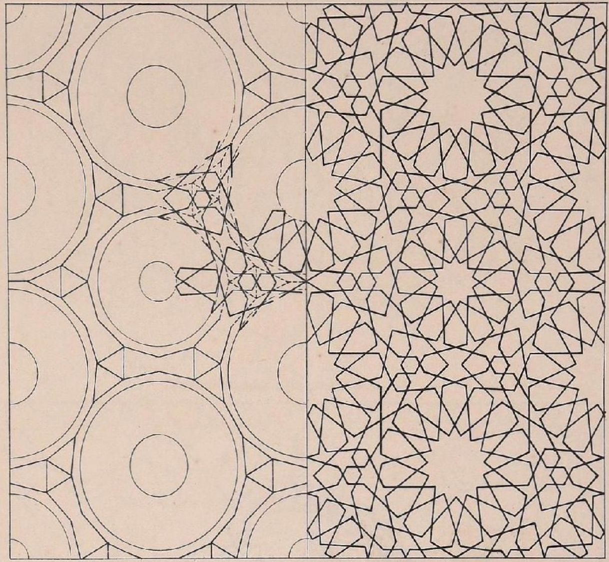

FIG. 39 Arabesque pattern containing fifteen-pointed stars.

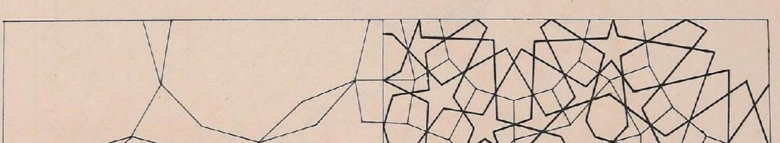

FIG. 40 Arabesque pattern containing 18-pointed stars.

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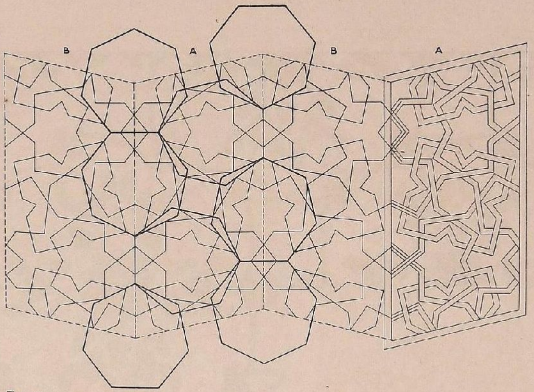

FIG 41

Pattern containing seven-pointed stars.

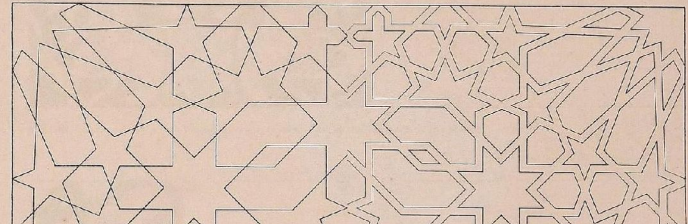

FIG. 42

Pattern containing octagons and irregular heptagons.

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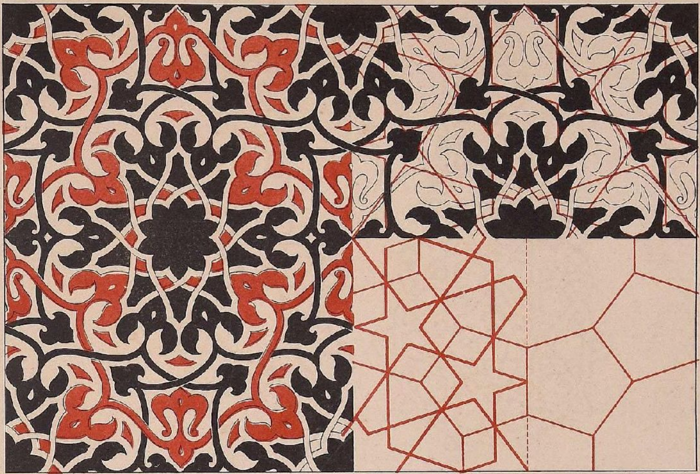

FIG. 43 Floral arabesque with decagonal pattern from which it is derived.

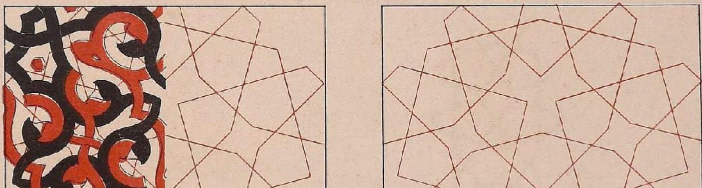

FIG. 44 Design from Gismah mosque, Cairo. (Bourgoin Pl. 44.) Pattern occuring in—

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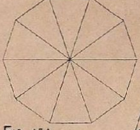

FIG. 45A

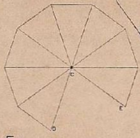

FIG. 45B

Decagon and a decagon with two triangles cut out.

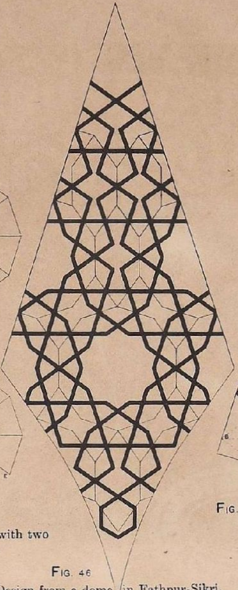

FIG. 46

Design from a dome in Fathpur-Sikri.

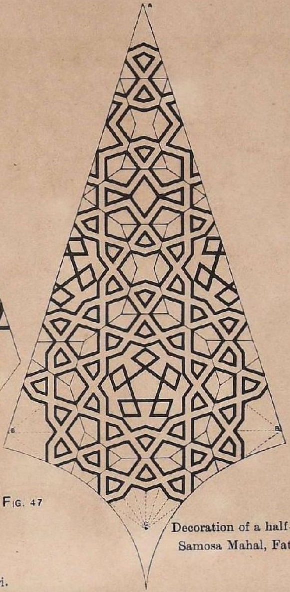

FIG. 47

Decoration of a half-dome in the Samosa Mahal, Fathpur-Sikri.

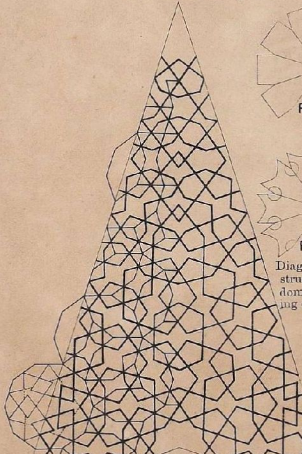

FIG. 48

Decoration of a half-dome in the Agra Gate of the outer wall of Fathpur-Sikri.

FIG. 49A

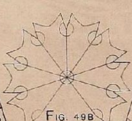

FIG. 49B

Diagram of the structure of a dome of increasing curvature.

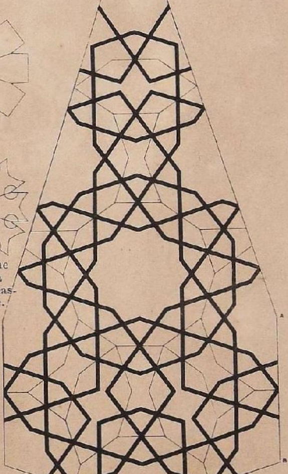

FIG. 50

Design from the interior of the dome surmounting the cupola on the Hiran Minar, Fathpur-Sikri.

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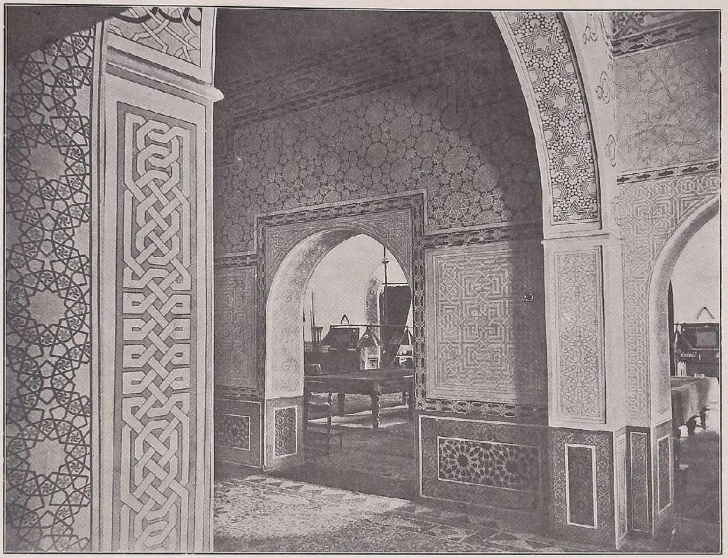

FIG. 51.

FIG. 52.

THE CLUB, AGRA.